BARKER (Geo. F.)

SOME MODERN ASPECTS OF THE LIFE-QUESTION.

ADDRESS

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PRESIDENT OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,

BOSTON MEETING, AUGUST, 1880.

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George F. Barker.

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Professor GEORGE F. BARKER,

THE RETIRING PRESIDENT OF THE ASSOCIATION.

SOME MODERN ASPECTS OF THE LIFE-QUESTION.

THE NUMBER OF ROOTS IN OUR EQUATION OF LIFE INCREASES THE DIFFICULTY OF SOLVING IT, BUT BY NO MEANS PERMITS THE ACCEPTANCE OF THE LAZY ASSUMPTION THAT IT IS ALTOGETHER INSOLUBLE OR REDUCES A SAGACIOUS GUESS TO THE LEVEL OF THE PROPHECY OF A QUACK.—*Haughton.*

Ladies and Gentlemen of the American Association for the Advancement of Science:—

The discovery of new truth is the grand object of scientific work. The exultation of feeling which comes from the possession of a fact, which, now, for the first time, he makes known to men, must ever be the reward of the scientific worker. As investigators and as students of science we are met here to-day at this our annual session. Each of us during the past year has been endeavoring to push outward further into the unknown, the boundary of present knowledge. When, therefore, we thus meet together it is fitting that, from time to time, our attention should be called to the progress which has been made along some one of the various lines of research, and to the milestones which mark the epochs of advance along the way which science has travelled. Moreover, we may profitably sum up at such times the work done in particular directions, and encourage ourselves with pro-

spective and retrospective glances. In these summings up, however, a difficulty arises. The range of modern scientific thought includes an immense area. The field of knowledge is already so vast, that, seen from the vertical distance necessary to make a wide survey, that small portion of it which is familiar to any one individual is scarcely visible. In consequence, to use a mechanical figure, the solid contents of a man's acquirements being given, the depth thereof is inversely as the area covered. He, therefore, who undertakes to speak even for one single department of science distributes his stock of knowledge over so broad a surface that in places it must become dangerously thin. It is, therefore, with a very keen sense of the temerity involved in the undertaking, that I ask your attention during the hour allotted me, to some points which appear to me to have been recently gained in the discussion of the question of life.

My friend and predecessor, Professor Marsh, opened his excellent address at Saratoga with the question "What is Life?" In a somewhat different sense I too ask the same question. But I fear it is only to echo his reply, "the answer is not yet." The result, however, cannot long be doubtful. "A thousand earnest seekers after truth seem to be slowly approaching a solution." And though the *ignis fatuus* of life still dances over the bogs of our misty knowledge, yet its true character cannot finally elude our investigation. The progress already made has hemmed it in on every side; and the province within which exclusively vital acts are now performed, narrows with each year of scientific research.

What now are we to understand by the word "Life" in this discussion? A noteworthy parallel is disclosed in the progress of human knowledge between the ideas of life and of force.[1] Both conceptions have advanced, though not with equal rapidity, from a stage of complete separability from matter to one of complete inseparability. Life is now universally regarded as a phenomenon of matter, and hence of course, as having no separate existence. But there still exists a certain vagueness in the meaning of the term "life." Two distinct senses of this word are in use; the one metaphysical, the other physiological. The former, synonymous with mind and soul, at least in the higher animals, has been evolved from human consciousness; the latter has arisen from a more or less careful investigation of the phenomena of living beings. It need scarcely be said that it is in the sense last men-

tioned that the word "life" is used in science.[2] The conception represents simply the sum of the phenomena exhibited by a living being.

Moreover, the progress which has been made in the solution of the life-question has been gained chiefly by investigation of special functions. But the functions of a vital organism are themselves vital. What then is the meaning of "vital" as applied to a function? Fortunately the answer is not difficult. "Life," says Küss, the distinguished Strasbourg physiologist, "is all that cannot be explained by chemistry or physics."[3] Guided by such a definition the work of the physiological investigator is simple. He has only to test each separate operation which he finds going on in the organism and to declare whether it be chemical or physical. If it be either, then since each function is non-vital, the entire organism must be non-vital also. Hundreds of able investigators, provided with the most effective appliances of research, are now in full cry after the life principle. Naturally, a vast amount of collateral knowledge is accumulated in the process. The quantitative as well as the qualitative relations of things are fixed and many important facts are collected.

With the object in view thus clearly defined, we are not surprised that great progress has been made. A vital process, like the catalytic ones of the older chemistry, was found by such research to be simply a process which, for want of sufficient investigation, is not yet understood.[4] While therefore, undoubtedly, much work yet remains to be done in the realm still called vital, the prophetic vision is already bright which will witness the last traces of inexplicable phenomena vanish and the words expressing them relegated to the limbo of the obsolete.

As a first result of recent work, the living organism has been brought absolutely within the action of the law of the Conservation of Energy. Whether it be plant or animal, the whole of its energy must come from without itself, being either absorbed directly or stored up in the food.[5] An animal like a machine, only transforms its energy. Lavoisier's guinea-pig placed in the calorimeter gave as accurate a heat-return for the energy it had absorbed in its food, as any thermic engine would have done.[6] But the parallel goes further. The mechanical work of an engine is measured by the loss of its heat and not of its substance. So the mechanical or intellectual work of a living being is measured

by the amount of carbon rather than the amount of nitrogen which is excreted.[7] The energy evolved daily by the human body would raise it to a height of about six miles.[8]

But beside heat, work may be the outcome of the organism; and this through the agency of the muscles. Their absolute obedience to mechanical law in their mode of action has been admirably established by Haughton.[9] The work a muscle does, it does in contracting. It is to the mechanism of muscle-contraction that we are indebted for another illustration of our subject.

When work is done by a muscle in contracting, three changes are observed to take place normally in its tissue. First, there is a loss of its electric tension; second, there is an evolution of heat in it; and third, carbon dioxide appears there, and its reaction, before neutral, becomes acid.[10]

Matteucci was the first to observe and to call attention to the remarkable similarity in structure and in the mechanism of operation, between striated muscular fibre and the electric organ of certain fishes.[11] Recently, Marey has repeated and extended his observations.[12] In structure, the electric organ is made up, like the muscle, of columnar masses each separable transversely into vesicular sections. In a torpedo weighing seventy-three pounds, there were 1182 of these columns in each of the two organs, with 150 sections, on an average, in each column.[13] In the muscles which bend the fore-arm, there are 798,000 fibrillæ.[14] As to the mechanism, alike in muscle and in electric organ, an electric current stimulates action on opening and on closing the circuit, but not when it is flowing; the same phenomena take place in both with the direct and with the inverse current; both are reflex; stimulation of the electric nerve produces discharge, as that of the motor nerve causes muscular shock; an entire paralysis follows nerve-section; curare paralyzes both; and tetanus results in both from rapid currents or from strychnine.[15]

Still more striking analogies are furnished by the investigation of the susurrus or muscular sound, first noticed in 1809 by Wollaston.[16] This sound is produced by all muscles when in the state of contraction, the pitch of the note being not far from thirty vibrations per second. It is evidently only the intermittent contraction of the muscular fibre. A single excitation produces a muscular shock. As this production requires from eight to ten hundredths of a second, it is evident that if another stimulus be

applied before the first has disappeared the two will coalesce; and when twenty per second reach the muscle it becomes permanently contracted or tetanized.[17] By means of a very sensitive myograph, Marey has found that in voluntary contraction the motor nerves are the seats of successive acts, each of which produces an excitation of the muscle. In 1877, Marey examined similarly the discharge of the torpedo and found a most complete correspondence between it and muscular contraction.[18] Since electric tension disappears from a muscle during contraction, does not the analogy suggest strongly that, like the discharge of the electric organ of the torpedo, muscular contraction is an electrical phenomenon?[19]

Granting electric discharge to be a necessary concomitant of muscle-contraction, what is the origin of this electricity? That it is not carried to the muscle by the nerves follows from the fact that a muscle will still contract when deprived of all its nerve-fibres, or when these are paralyzed by curare.[20] It must therefore be generated within the muscle itself.[21] To reach a solution of the problem we must obviously follow the analogies of its production elsewhere.

Perhaps no single question in physics has been more keenly discussed than this one of the origin of electric charge. The memorable conflict between Galvani and Volta, between animal electricity and the electricity of metallic contact, succeeded by the even more triumphant overthrow of the latter and the establishment ultimately by Faraday, of the electro-chemical theory; these are facts fresh in all our memories. The justice of time however in this case, if it has been tardy, has been none the less sure. The experiments of Thomson have vindicated Volta and established the contact theory as a *vera causa*. And more curiously still, it now appears to be proved that both contact and chemical action underlie the production of that very animal electricity so stoutly battled for by Galvani and his associates.

Volta's experiments to prove that a difference of potential is developed by the contact of two heterogeneous metals were not crucial. But Thomson, repeating them with the aid of more delicate apparatus, has shown that whenever copper and zinc are brought in contact, the copper becomes negative to the zinc. In proof that the chemical action of atmospheric moisture was not the cause of the phenomenon, he showed that when a drop of water served to connect the copper and the zinc, no charge at all

was produced.[22] The fact may therefore be regarded as established, as the result of numerous and varied experiments, that a difference of electrical potential is always developed at the surfaces of contact of heterogeneous media. Not only is this true of solids in contact with solids, but also of solids in contact with liquids, and of liquids in contact with each other.[23] Of course the production of electricity by contact must result from a loss of energy elsewhere. In the opinion of Cumming, it is the loss of energy which is owing to the unsymmetrical swinging of the molecules on the two sides of the surfaces of contact, which reappears as difference of potential between the solids or as the energy of electrical separation.[24]

But we may carry the sequence yet another step backward. The energy which is thus lost at the surfaces of separation must be heat, and this junction must be cooled thereby. Thus the production of thermo-electricity is seen only to be a special case of a general law, a view to which the well-known Peltier effect gives support. In this phenomenon, when two metals are joined together in the form of a ring and one junction is heated, a current is produced which cools the other junction.[25] From a study of these conditions, Thomson has concluded that the absorption of heat in a thermo-electric circuit varies for different metals with the direction of the current. Thus in iron, the current from hot to cold absorbs heat, while in copper the current which absorbs heat is from cold to hot.[26] In entire accordance with these results, are the conclusions recently reached by Hoorweg. Whenever two conductors come into contact, motion of heat results in the development of electricity, the current produced existing at the cost of heat at one part of the point of contact, and evolving heat at the other for a result. Hence all voltaic currents are thermo-currents.[27]

To return to the muscle, it must now be apparent that the electrical charge which appears in its fibre may have its origin in so purely a physical cause as the contact of the heterogeneous substances of which the tissue is built up; the maintenance of this charge being effected by chemical changes going on constantly in the substance of the muscle, by which the carbon dioxide is produced, which is shown to be a measure of the work done.[28]

Conceding then, that a muscular contraction is conditioned upon an electric discharge, by what mechanism is the contraction effected? Prevost and Dumas supposed each particle of a

muscular fibril to be magnetic. Such a row of particles would indeed attract each other when magnetized and shorten the length of the whole fibril. But the force of contraction would increase as the length diminished; whereas the fact in the case of the muscle is precisely the reverse.[29] Hence Matteucci supposed that electrification of the muscular fibre produces a repulsion between its elements, the subsequent return of this fibre, in virtue of its proper elasticity,[30] constituting the muscular contraction. Radcliffe's theory is of more recent date and is somewhat analogous. He maintains that each fibre of the muscle, together with its sheath, constitutes a condenser. When charged, the attraction of the two electricities compresses the fibre laterally and thus elongates it. When discharge takes place the normal elasticity of the fibre produces the contraction.[31] Assuming, however, that the electrical phenomena take place during the latent period only, other theories of muscular contraction regard these phenomena as simply preparatory, the contraction itself being mechanical. Thus Marey[32] likens the muscular fibre to a string of India rubber which, when stretched, contracts upon warming it; thus transforming heat directly into work. Rouget contends that the muscular fibre is a true spiral spring, which, actively distended during the repose of the muscle, returns upon itself at the moment of contraction; muscular contractility being thus a purely physical property of elasticity. Engelmann, observing that during contraction changes take place in the doubly-refracting power of the alternate disks of the fibril, supposes muscular contraction to result from a passage of water from the isotropic layers into the anisotropic or doubly-refracting ones; thus osmotically increasing the volume of the latter. By this means the ellipsoidal doubly-refracting particles are converted into spherical ones; and since the longer axes of the ellipsoids are parallel to the length of the fibre, the muscle is thereby shortened.[33]

From this brief review, does it not seem probable that the phenomenon of muscular contraction may be satisfactorily accounted for without the assumption of "vital irritability," so long invoked?[34] May it not be conceded that the theory that muscular force has a purely physical origin is at least as probable as the vital theory?

Time would fail me to discuss the many other phenomena of the living body which have been found on investigation to be non-

vital. Digestion, which Prout said it was impossible to believe was chemical,[35] is now known to take place without the body as well as within it, and to result from non-vital ferments.[36] Absorption is osmotic and its selective power resides in the structure of the membrane and the diffusibility of the solution.[37] Respiration is a purely chemical function. Oxyhæmoglobin is formed wherever hæmoglobin and oxygen come in contact and the carbon dioxide of the serum exchanges with the oxygen of the air according to the law of gaseous diffusion.[38] Circulation is the result of muscular effort both in the heart and the capillaries, and the flow which takes place is a simple hydraulic operation.[39] Even coagulation, so tenaciously regarded as a vital process, has been shown to be purely chemical. Upon the hypothesis of Schmidt it results from the union of two proteids, fibrinogen and fibrinoplastic substance.[40] According to the later theory of Hammarsten, fibrin is produced from fibrinogen by the action of a special ferment.[41]

There is another function which should by no means be omitted from our consideration. This function is that of the nervous system. In structure, this system is well known to us all. In composition, it is made up essentially of a single substance, discovered by Liebreich[42] and called protagon, the specific characters of which have lately been confirmed by Gamgee.[43] In function, the nerve-cell and the nerve fibre are occupied solely in the production, the reception and the transmission of energy, which is believed to be electrical. There is evidently a close analogy between the nerve and the muscle, the nerve-fibre like the fibrilla being composed of cells, and having a positive electric charge upon the exterior surface the tension of which is one-tenth of a volt.[44] Indeed a piece of nerve removed from the body exhibits nearly the same electric phenomena as a piece of muscle. Haughton attributes *tinnitus aurium* to the vibration of nerve cells.[45]

The main objection raised to the electrical character of nerve-energy is based upon its slow propagation.[46] Though thirty-six years ago Johannes Müller predicted[47] that the velocity of nerve transmission never could be measured, yet Helmholtz accomplished the feat very soon afterward.[48] His results, like those of subsequent experimenters, show that the velocity of propagation of the nervous influence along a nerve, like that of electric transmission, is only about 26 to 29 metres in a second.[49] But it should be borne in mind, as Lovering has pointed out, that electricity has no

velocity, in any proper sense.[50] That since the appearance of an electrical disturbance at the end of a conductor depends upon the production of a charge, the time of this appearance will be a joint function of the electrostatic capacity of the conductor and of its resistance. Since each of these values is directly proportional to length, it follows that the time of transmission will vary as the square of the length of the conductor. While therefore, in Wheatstone's experiment, he found that electricity required rather more than one-millionth of a second to pass through one-quarter of a mile of wire, it does not follow that it would traverse 288,000 miles in one second, as he assumed. Indeed, as Lovering has shown, its actual velocity would be only 268 miles in an entire second. Hence the marvellous discrepancies which have been observed in the results of experiments made to determine the velocity of electricity on long wires are explained.[51]

In the nerve itself, therefore, the velocity of transmission may be supposed to be the less as its resistance is greater. Now, Weber has shown that animal tissues in general have a conductivity only one fifty-millionth of that of copper.[52] And Radcliffe found that a single inch of the sciatic nerve of a frog measured 40,000 ohms; a resistance eight times that of the entire Atlantic cable.[53] In experimenting to confirm the above law of velocity, Gaugain measured the time of transmission of the electric current through a cotton thread 1.65 metres long and found it to be eleven seconds. Two similar threads placed consecutively, thus forming a conductor twice as long, required forty-four seconds for the passage of the current; or four times as long. From these data the apparent velocity in the short thread is at the rate of only 0.15 metre in one second; and in the long one only about half this rate, of course.[54] The real velocity in both cases is the same, 0.5 metre per second. Hence the fact that the energy of nerve moves at the rate of only 28 metres per second is really no proof that it is not electricity.[55]

But even if it shall appear that the nervous energy is not electrical, the argument is not weakened, since on no theory yet proposed is it assumed to be vital. Du Bois Reymond, while maintaining that "it would be rash entirely to dismiss the notion of electricity being concerned, and even playing an important part, in the internal mechanism of the nerves," yet, assuming its low velocity to be fatal to its electrical character, suggests that

the nervous agent "is some internal motion, perhaps even some chemical change of the substance itself, contained in the nerve-tubes, spreading along the tubes both ways from any point where the equilibrium has been disturbed." And Spencer has advanced the view that "a nervous disturbance travels as a wave of molecular change;" that "a nervous discharge is a wave of isomeric transformation."[56]

The higher functions of the nerve-cell, those connected with mental processes, is a field too vast to be entered at this time. The double telegraph line of nerve, motor and sensor in their effect, but, as is now conceded,[57] precisely alike in function, are the avenues of ingress and egress. In the acts denominated reflex, the stimulus reaches the spinal cord only and the action is automatic and unconscious. Should the impression ascend higher to the sensory ganglia, the action is now conscious though none the less automatic. Finally, should deliberation be required before acting, the message is sent to the hemispheres by the sensory ganglia and will operates to produce the act. Based on principles already established by investigation, a true psychology is coming into being, developed by Bain, Maudsley, Spencer and others.[58] A physiological classification of mental operations is being formed which uses the terms of metaphysical psychology, but in a more clearly defined sense.[59] Emotion, in this new science, is the sensibility of the vesicular neurin to ideas. Memory, the registration of stimuli by nutrition. Reflection is the reflex action of the cells in their relations in the cerebral ganglia. Attention is the arrest of the transformation of energy for a moment. Ratiocination is the balancing of one energy against another. Will is the reaction of impressions outward. And so on through the list.

Among the physical aspects of the mind-question, the problem of the quantitative changes which take place in the organism is a very curious and interesting one. That the energy of the brain comes from the food will be disputed by no one in these days. Hence, the brain must act like a machine and transform energy. There is then a purely physiological representation of mental action, concerned with forces which are known and measurable. The researches of Lombard long ago showed the concomitant heat of mental action.[60] Recent researches are equally interesting, which show that mental operations are not instantaneous but require a distinct time for their performance. By accurate chronographic

measurement, Hirsch and Donders have shown that an irritation on the head is answered by a signal with the hand only after one-seventh of a second; that a sound on the ear is indicated by the hand in one-sixth of a second; and that when light irritates the eye, one-fifth of a second elapses before the hand moves.[61] The mechanism of such a process is the following:[62] Suppose the sound "A" is heard by the ear. After a latent period it is translated to some nerve cells and hence to the brain. From the brain it goes to other cells, ganglion cells, and to other nerves, and then to the different muscles of the chest and larynx, and then follows the audible response "A." Now since this whole process requires only one-sixth of a second, the question arises, how much of it is psychical. To answer it, the experiment is repeated but with this difference, that the particular sound to be used is unknown to the experimenter. Before the sound can be repeated by him therefore, a distinct act of discrimination is required, and the time taken is longer. Calling the time in the first experiment a, and in the second b, the difference $b—a$ is the time required for two distinct actions: one, that of distinguishing the sound, and the other, that of willing the corresponding movement. If now it be agreed that only the sound "A" shall be responded to when called, these may be separated since no other sound being responded to the latter action is eliminated. If the time now required be called c, the difference $c—a$ represents the time required for forming a judgment, and $c—b$ the time required for a volition. In making these measurements, Donders used an instrument devised by him, called a noëmotachograph, and also a modification of it called a noëmotachometer.[63] By these instruments different points of the body can be irritated, different sounds can be produced, and different colors or letters can be shown, all by the electric spark. By subtracting the simple physiological time from the time given in any experiment, the time necessary for recognition may be obtained. By an addition to the apparatus, a second stimulus may be made to follow the first, either on the same or on a different sense; thus enabling the time necessary for a simple thought to be determined. As a result of his experiments, Donders found that the value $b—a$ in the case of a simple dilemma was seventy-five thousandths of a second, this being the time required for recognition and subsequent volition. In the same way $c—a$ has been shown to be forty-thousandths of a

second, being the time required for simple recognition; there is left thirty-five thousandths of a second as the time required for volition. Moreover, by independent measurement with the noëmotachometer, exactly the same time, one twenty-fifth of a second, is found necessary to enable a judgment to be formed about the priority of two impulses acting on the same sense. If they act on different senses, more time is necessary. So also more time is required to recognize a letter by seeing its form than by hearing its sound. A man of middle age then, thinking not so very quickly, requires one twenty-fifth of a second for a simple thought.

Another important fact concerning nervous action is that its amount may be measured by the quantity of blood consumed in its performance. Dr. Mosso of Turin has devised an apparatus called the Plethysmograph—drawings of which were exhibited at the London Apparatus Exhibition of 1876—designed for measuring the volume of an organ.[64] The fore-arm, for example, being the organ to be experimented on, is placed in a cylinder of water and tightly enclosed. A rubber tube connects the interior of the cylinder with the recording apparatus. With the electric circuit by which the stimulus was applied to produce contraction, were two keys, one of which was a dummy. It was noticed that, after using the active key several times, producing varying current strengths, the curve sank as before on pressing down the inactive key. Since no real effect was produced, the result was caused solely by the imagination, blood passing from the body to the brain in the act. To test further the effect of mental action, Dr. Pagliani, whose arm was in the apparatus, was requested to multiply 267 by 8, mentally, and to make a sign when he had finished. The recorded curve showed very distinctly how much more blood the brain took to perform the operation. Hence the plethysmograph is capable of measuring the relative amount of mental power required by different persons to work out the same mental problem. Indeed Mr. Gaskell suggests the use of this instrument in the examination room, to find out, in addition to the amount of knowledge a man possesses, how much effort it causes him to produce any particular result of brain-work. Dr. Mosso relates that while the apparatus was set up in his room in Turin, a classical man came in to see him. He looked very contemptuously upon it and asked of what use it could be, saying that it couldn't do anybody any good. Dr. Mosso replied, "Well now, I can tell you

by that whether you can read Greek as easily as you can Latin." As the classicist would not believe it, his own arm was put into the apparatus and he was given a Latin book to read. A very slight sinking of the curve was the result. The Latin book was then taken away and a Greek book was given him. This produced immediately, a much deeper curve. He had asserted before that it was quite as easy for him to read Greek as Latin and that there was no difficulty in doing either. Dr. Mosso, however, was able to show him that he was laboring under a delusion. Again, this apparatus is so sensitive as to be useful for ascertaining how much a person is dreaming. When Dr. Pagliani went to sleep in the apparatus, the effect upon the resulting curve was very marked indeed. He said afterward that he had been in a sound sleep and remembered nothing of what passed in the room—that he had been absolutely unconscious; and yet, every little movement in the room, such as the slamming of a door, the barking of a dog, and even the knocking down of a bit of glass, were all marked on the curves. Sometimes he moved his lips and gave other evidences that he was dreaming; they were all recorded on the curve, the amount of blood required for dreaming diminishing that in the extremities. The emotions too left a record. When only a student came into the room, little or no effect appeared in the curve. But when Professor Ludwig himself came in, the arteries in the arm of the person in the apparatus contracted quite as strongly as upon a very decided electrical stimulation.

In an address of the retiring President of this Association, delivered but a few years ago, I find this sentence: "Thought cannot be a physical force, because thought admits of no measure."[65] In the light of the rapid advances lately made in investigating mental action, we see that in two directions at least, in its rate of action and of its relative energy, we may already measure thought, as we measure any other form of energy, by the effects it produces.

Passing now to the consideration of the general question of the transformation of energy which is effected by living beings, attention may be called to one or two points in general physics, as bearing upon its solution. The great law of the dissipation of energy, as modified by Thomson from the statement of Clausius, is thus stated: "The entropy of the universe tends to zero."[66] In other words, the energy of the universe available for transmutation

is approaching extinction. This conclusion is based upon the fact that while every form of energy can be completely converted into heat, heat cannot be completely converted into other forms of energy, nor these into each other. Hence it arises that energy is being gradually dissipated as heat. Moreover, since transformation can only result when heat passes from a higher to a lower temperature, it follows that when that perfect equilibrium of temperature is reached toward which events are tending, there can be no other energy than heat; and this absolutely inconvertible, irrecoverable. To apply this law to the present case, the muscle, for example, is a machine for transforming the energy of food into work. Since, consequently, this conversion is not complete, it follows that heat must appear as a necessary result of muscular action. The heat of animal life, consequently, is not heat especially provided; it is simply the heat which inevitably results from an incomplete conversion of energy.

Again, the form of chemical action generally assumed by physiologists to account for the energy of the living animal has been chemical union, oxidation.[67] But the science of thermo-chemistry, as developed in late years by Berthelot and Thomsen,[68] has proved that direct union of chemical substances may not only not evolve heat, but may actually absorb it. It appears, too, that thermal changes accompany all forms of chemical change, those of decomposition and exchange as well as those of synthesis. The animal absorbs highly complex substances as food, capable of innumerable stages of retrogressive metamorphosis before elimination. In each of these stages energy may be evolved, this energy being that successively stored up by the plant when these changes were repeated in the inverse order.

Another point of interest has reference to the modern views of capillarity. In 1834, J. W. Draper showed that capillarity is an electrical phenomenon.[69] Quite recently, Lippmann has developed and extended this view and fully confirmed it.[70] Whenever the free surface of a liquid, curved by capillary action, is electrified it changes its form; and conversely, when such a surface is made by mechanical means to change its form, an electromotive force is developed. Based upon this principle Lippmann constructed a capillary reversible engine and an extremely sensitive capillary electrometer. The former, when a current of electricity was applied to it, developed mechanical work and ran as a motor.

When turned by hand, it became an electromotor. In the animal organism there are it is true but a few free surfaces where this action can take place. But Gore has shown that the same phenomenon appears between two liquids in contact, their boundary being altered in character by electrification.[71] Indeed, when we consider the production of electricity by osmose, and of heat and electricity both, by imbibition, both capillary phenomena,[72] the wonder is not that so much electrical energy is evolved by the organism, but that it is so little. If the physical and chemical changes which take place within the body took place without it, there would be an abundant evolution of energy. Can we doubt that these changes are the cause of the energy exhibited by the organism?

Thus far, when we have spoken of a living being, we have had reference to the organism as a whole, and this of a rather complex kind. In this view of the case, however, we find that biological microscopists do not agree with us. "The cell alone," says Küss, "is the essentially vital element."[73] Says Beale,—"There is in living matter nothing which can be called a mechanism, nothing in which structure can be discerned. A little transparent colorless material is the seat of these marvellous powers or properties by which the form, structure and function of the tissues and organs of all living things are determined."[74] And again, "However much organisms and their tissues in their fully formed state may vary as regards the character, properties and composition of the formed material, all were first in the condition of clear, transparent, structureless, formless living matter."[75] So Ranvier:[76] "Cellular elements possess all the essential vital properties of the complete organism." And Allman, in his address as President of the British Association last year, is still more explicit.[77] "Every living being," he says, "has protoplasm as the essential matter of every living element of its structure." "No one who contemplates this spontaneously moving matter can deny that it is alive. Liquid as it is, it is a living liquid; organless and structureless as it is, it manifests the essential phenomena of life." "Coextensive with the whole of organic nature — every vital act being referable to some mode or property of protoplasm, it becomes to the biologist what the ether is to the physicist." From these quotations it would seem that even in the highest animal there is nothing living but protoplasm or germinal matter, "transparent,

colorless, and, as far as can be ascertained by examination with the highest powers of the microscope, perfectly structureless. It exhibits these same characters at every period of its existence." Neither the contractile tissue of the muscle, the axis-cylinder of the nerve, nor the secreting cell of the gland, is living, according to Beale.[78] Hence it would be fair to draw the inference that vital force should not be required to explain the phenomena of the non-living matter of the body, such as the contraction of the muscle or the function of the nerve. If this be conceded it is a great point gained; since the phenomenon of life becomes vastly simplified when we have to account for it only as exhibited in this one single form of living matter, protoplasm. In describing its properties, Allman includes this remarkable mobility, these spontaneous movements, and says that they result "from its proper irritability, its essential constitution as living matter." "From the facts there is but one legitimate conclusion, that life is a property of protoplasm." Beale, however, will not allow that life is "a property" of protoplasm. "It cannot be a property of matter," he says, "because it is in all respects essentially different in its actions from all acknowledged properties of matter."[79] But the properties of bodies are only the characters by which we differentiate them. Two bodies having the same properties would only be two portions of the same substance. Because life, therefore, is unlike other properties of matter, it by no means follows that it is not a property of matter.[80] No dictum is more absolute in science than the one which predicates properties upon constitution. To say that this property exhibited by protoplasm, marvellous and even unique though it be, is not a natural result of the constitution of the matter itself, but is due to an unknown entity, a *tertium quid*, which inhabits and controls it, is opposed to all scientific analogy and experience. To the statement of the vitalist that there is no evidence that life is a property of matter, we may reply with emphasis that there is not the slightest proof that it is not.

Chemistry tells us that complexity of composition involves complexity of properties. The grand progress which Organic Chemistry has made in recent times has been owing to the distinct recognition of the influence of structure upon properties. Isomerism is one of its most significant developments. The number of possible isomers increases enormously with the complexity of

the molecule. Granted that we now know several of the proteid group of substances:[81] how many thousands may there be yet to know? Bodies of such extreme complexity of constitution may well have an indefinite number of isomers. Not only does chemistry not say that there cannot be such a thing but she encourages the expectation that there will yet be found the precise proteid of which the phenomena of protoplasm are properties. The rapid march of recent organic synthesis makes it quite certain that every distinct chemical substance of the living body will ultimately be produced in the laboratory;[82] and this from inorganic materials. Given only the exact constitution of a compound, and its synthesis follows. When therefore, the chemist shall succeed in producing a substance constitutionally identical with the protoplasmic mass, there is every reason to expect that it will exhibit all the phenomena which characterize its life; and this equally whether protoplasm be a single substance or a mixture of several representative substances.

But here a word should be said concerning a remarkable physical condition assumed by matter in organized beings. Graham, in 1862, drew the sharp line which separates colloid from crystalloid matter.[83] His researches have proved, says Maudsley,[84] "the necessity of considerable modification in our usual conception of solid matter. Instead of the notion of inert impenetrable matter, we must substitute the idea of matter which in its colloidal state is penetrable, exhibits energy, and is widely susceptible to external agents; 'its existence being a continued metastasis.' This sort of energy is not a result of chemical action, for colloids are singularly inert in all ordinary chemical relations, but is a result of its unknown molecular constitution; and the undoubted existence of colloidal energy in organic substances, which are usually considered inert and called dead, may well warrant the belief of its larger and more essential operation in organic matter in the state of instability of composition in which it is when under the condition of life. Such energy would then suffice to account for the simple uniform movements of the homogeneous substance of which the lowest animal consists; and the absence of any differentiation of structure is a sufficient reason for the absence of any localization of function and of the general uniform reaction to different impressions." Graham himself says that the colloidal state may be looked upon "as the probable primary source of the force appearing in the phenomena

of vitality."[85] The colloidal condition is the dynamical state of matter; the crystalloidal the static. The former, which is the rule in the organic kingdom of nature, is the exception in the inorganic. Aluminum and ferric hydrates, silicic acid and a few other inorganic substances, exist in the colloid condition. From analogy there would seem to be but little doubt that the colloid state of these bodies differs from their crystalloid state merely in the size of the molecule. In other words opal, which is colloid silica, is a polymer of quartz. If this theory be true there can be no doubt of the vastly greater complexity of a colloidal proteid molecule than of a crystalloid one. Now it is a very significant fact, in this connection, that not a single organic colloid has ever been synthesized. Gelatin, which is one of the best examples of a colloid, has a comparatively simple structure. And, although Hunt suggested, many years ago, that gelatin was probably an amido-derivative of the sugar group,[86]—a theory subsequently partially confirmed by Gibbs—yet no inverse process has yet given us this substance. That matter in the crystalloid and the colloid forms may be chemically identical, differing only in the size of its molecule, may be quite possible. But it is also possible that the difference may be a physical one. To produce the colloid state from the crystalloid is by no means beyond the power of science. We qualify our previous statement then only so far as to say that when the chemist produces a body in the colloidal form, having the identical constitution of protoplasm, there is every reason to believe that it will have the vital properties of protoplasm.

The important question now arises whether, since the protoplasm of animals is identical with that of vegetables, and the latter is the food of the former, any energy whatever is stored up by the animal as such. That this identity exists would seem satisfactorily established. Though the protoplasm of vegetables is enclosed within a cellulose bag, it is, says Allman, only a closely imprisoned rhizopod.[87] In the Nitella, it shows all its characteristic irritability, and from Vaucheria it escapes to exhibit all its amœboid movements. Spores swim about by cilia or flagella, and the cell-division of the one kingdom is the same as that of the other. In plants, however, protoplasm seems to be associated with chlorophyll, whose function was for a long time supposed to be to decompose carbon dioxide under the influence of sunlight. But Draper in 1872, showed that this decomposition took place before the chlo-

rophyll was formed.[88] Recent researches suggest that the function of chlorophyll may be wholly protective.[89] The assimilative power of the protoplasm reaches its maximum in the orange and yellow rays. Now Bert has shown that the absorption band in the chlorophyll spectrum is in the exact position of this maximum.[90] Hence, Gautier believes that this substance acts as a regulator of plant respiration, the greater or less amount of luminous energy thus absorbed and transformed, being utilized by the protoplasm and stored up.[91] Growth and cell-division, however, are independent of orange light and hence of chlorophyll. In the higher plants, these functions are performed by a separate and deep-lying set of cells. But in the lower, the same cell discharges both functions, assimilation going on in it during the day, and growth chiefly at night.[92] Sachs had already proved that the maximum growth of plants takes place just before daylight and the minimum in the afternoon. This retarding action of sunlight upon growth is as curious as it is unexpected. It now appears that in orange light plants assimilate — absorb carbon dioxide and evolve oxygen — but do not grow and are not heliotropic; while in blue light they are strongly heliotropic but do not give off oxygen.[93] Chlorophyll, however, is not confined to vegetables; infusoria, hydras, and certain planarian worms are green from the presence of this substance, and Geddes has shown that such animals, placed in the sunlight, give off a gas which is more than half oxygen.[94] These cells, moreover, contain starch granules.[95]

A still more striking evidence of this intimate relationship has been developed by Darwin, in his researches upon insectivorous plants.[96] Not only do these plants possess a mechanism for capturing insects, but they secrete a gastric juice which digests them. Nägeli has shown the presence of pepsin in yeast cells,[97] and attention has lately been called by Wurtz and others to the juice of the *Carica papaya* which contains a pepsin-like substance capable of peptonizing fibrin completely.[98] Moreover, there is the closest similarity between diastase and ptyalin;[99] and the milk of the cow-tree, recently examined by Boussingault[100] and found to resemble cream closely in composition, shows the presence of emulsifying agents in the vegetable kingdom analogous to those found in the pancreas of the animal.

Another most curious proof of the identity of animal and vegetable protoplasm has been given by Claude Bernard, who has shown

that both are alike sensitive to the influence of anæsthetics.[101] A sensitive plant exposed to ether no longer closes its leaflets when touched. Assimilation and growth, as well as germination, are arrested by chloroform. The yeast plant when etherized no longer decomposes sugar to produce alcohol and carbon dioxide; while the inversive and non-vital ferment still acts to convert the cane-sugar into glucose; precisely as under these circumstances, the diastasic ferment converts the starch of the seed into sugar.[102] By arresting anæsthetically the process by which carbon dioxide is absorbed and oxygen evolved, the true respiratory process, being less affected, now appears; and Schutzenberger has proved that the fresh cells of the yeast plant breathe like an aquatic animal.[103]

It would seem then that the protoplasmic life of animals is identical with that of plants; a certain measure of destructive metamorphosis taking place in each, evolving energy and producing carbon dioxide and water. When, however, this function is examined quantitatively, its maximum is seen to be reached in the animal. While the assimilative function characterizes the plant, the destructive function distinguishes the animal. Hence it is the function of the plant to store up energy, to produce the highly complex protoplasm. This, consumed by the animal as his food, continues his existence as a living being, the energy gradually set free by its successive steps of retrogressive metamorphosis, appearing as the work which he performs. If this view be correct, it would follow that every individual substance found in the animal—save only those which result from degradation—must be found in the plant upon which it feeds, and this is the fact. The myosin which Kühne[104] has shown to be the distinctive proteid of muscle, Vines has found in the aleuron grains of the lupine and the castor oil plant, along with vitellin, the special proteid of the vitellus.[105] The researches of Weyl and Bischoff have proved that gluten is formed in the dough of wheat flour by the action of a ferment upon the globulin-substance or plant-myosin which it contains,[106] precisely as Hammarsten has shown fibrin is produced in the action of a similar ferment upon fibrinogen.[107] Not only this; Hoppe Seyler has extracted from maize the identical substance which has been shown by Liebreich to be the essential chemical constituent of nerve tissue, protagon.[108]

The evidence then would seem to be conclusive that, since the protoplasm of the animal is identical with that of the vegetable,

the former must be derived from the latter. Hence the animal itself, though perhaps reconstructing more or less of the protoplasm of its food, really synthesizes none of this material. No energy therefore is stored up by the animal as such. Its total protoplasmic energy exists already in its food, in which it was stored up originally by the plant. Two inferences seem naturally to follow from this conclusion: 1st, that all the properties of animal protoplasm, and of the animal organism of which it constitutes the essential part, may be studied in the protoplasm of the plant; and 2d, that hence the solution of the life-question in the Myxomycetes will solve the life-problem for the highest vertebrate.[109]

Another consideration which must not be left out of the account in any discussion of the life-question is the potent influence of environment. Ordinary examples of this influence pass before our eyes every day. Heat necessitates the germination of the seed, and light causes plant assimilation. Gravity obliges the root to grow downward and the stem to ascend. Certain sensations from without excite inevitably muscular contraction; and a ludicrous idea may provoke laughter in defiance of the will. Epidemic and epizootic diseases show the dependence of function upon external conditions, and the germ theory illustrates the utter disproportionality of the cause to the effect.[110] The remarkable similarity in the periodicity observed between sunspots and the weather has been extended to include the appearance of locusts and the advent of the plague.[111] Even the body politic feels its influence, Jevons having established a coincident periodicity for commercial crises.[112]

The modern theory of energy, however, puts this influence in a still stronger light. As defined hitherto, energy is either motion or position; is kinetic or potential.[113] Energy of position derives its value obviously from the fact that in virtue of attraction it may become energy of motion. But attraction implies action at a distance; and action at a distance implies that matter may act where it is not. This of course is impossible; and hence action at a distance, and with it attraction and potential energy, are disappearing from the language of science. But what conception is it which is taking its place? By what action does the sun hold our earth in its orbit? The answer is to be found in the properties of the ether which fills all space. The existence of this ether,

the phenomena of light and electricity abundantly prove. While so tenuous that Astronomy has been taxed to prove that it exerts an appreciable resistance upon the least of the celestial bodies, its elasticity is such that it transmits a compression with a well nigh infinite velocity.[114] On the one hand, Thomson has determined its inferior limit, and finds that a cubic mile of it would weigh only one thousand-millionth of a pound;[115] on the other, Herschel has calculated that, if an amount of it equal in weight to a cubic inch of air be enclosed in a cubic inch of space, its reaction outward would be upward of seventeen billions of pounds.[116] Instead of being represented as is our air, by the pressure of a homogeneous atmosphere five miles in height, such a pressure would represent just such a homogeneous atmosphere five and a half billions of miles high, or about one-third the distance to the nearest fixed star! In Herschel's own words: "Do what we will, adopt what hypotheses we please, there is no escape in dealing with the phenomena of light, from these gigantic numbers; or from the conception of enormous physical force in perpetual exertion at every point through all the immensity of space."[117]

Now, as Preston has suggested,[118] if we regard this ether as a gas, defined by the kinetic theory that its molecules move in straight lines, but with an enormous length of free path, it is obvious that this ether may be clearly conceived of as the source of all the motions of ordinary matter. It is an enormous storehouse of energy, which is continually passing to and from ordinary matter, precisely as we know it to do in the case of radiant transmission. When potential energy becomes kinetic, the ether loses and the matter gains motion. When kinetic energy becomes potential, the lost energy of the matter is the motion gained by the ether. Before so simple a conception as this, both potential energy and action at a distance are easily given up. All energy is kinetic energy, the energy of motion. Giving now to the ether its storehouse of tremendous power, and giving to it the ability to transfer this power to ordinary matter upon opportunity, and we have an environment compared with which the strongest steel is but the breath of the summer air. In presence of such an energy it is that we live and move. In the midst of such tremendous power do we act. Is it a wonder that out of such a reservoir the power by which we live should irresistibly rush into the organism and develop the transmuted energy which we recognize in the phe-

nomena of life? Truly, as Spinoza has put it, "Those who fondly think they act with free will, dream with their eyes open."[119]

Such now are some of the facts and the theories to be found in the science of to-day concerning the phenomena of life. Physiologically considered, life has no mysterious passages, no sacred precincts into which the unhallowed foot of science may not enter. Research has steadily diminished day by day the phenomena supposed vital. Physiology is daily assuming more and more the character of an applied science. Every action performed by the living body is sooner or later, apparently, to be pronounced chemical or physical. And when the last vestige of the vital principle as an independent entity shall disappear from the terminology of science, the word "Life," if it remain at all, will remain only to signify, as a collective term, the sum of the phenomena exhibited by an active organized or organic being.

I cannot close without speaking a single word in favor of a vigorous development in this country of physiological research. What has already been done among us has been well done. I have said with diffidence what I have said in this address, because I see around me those who have made these subjects the study of their lives, and who are far more competent to discuss them than I am. But the laborers in the field are all too few, and the reasons therefor are not far to seek. One of these undoubtedly is the high scientific attainment necessary to a successful prosecution of this kind of investigation. The physiological student must be a physicist, a chemist, an anatomist and a physiologist all at once. Again, the course of instruction of those who might fairly be expected to enter upon this work, the medical students of the country, is directed toward making them practitioners rather than investigators. In the third place the importance of physiological studies in connection with zoölogical research is only beginning in this country to receive the share of attention it deserves. I well remember the gratification I experienced in 1873 upon receiving a letter from Professor Louis Agassiz, announcing his intention to have lectures at Penikese upon physiological chemistry; a new departure for those times. In this view of the case it seems very appropriate that a new subsection of this Association should be just now in process of formation. We welcome warmly the body of men who form it and we predict that from the new subsection of Anatomy and Physiology most valuable contributions will be received for our proceedings.

It is a beautiful conception of science which regards the energy which is manifested on the earth as having its origin in the sun. Pulsating awhile in the ether-molecules which fill the intervening space, this motion reaches our earth and communicates its tremor to the molecules of its matter. Instantly all starts into life. The winds move, the waters rise and fall, the lightnings flash and the thunders roll, all as subdivisions of this received power. The muscle of the fleeing animal transforms it in escaping from the hunter who seeks to use it for the purpose of his destruction. The wave that runs along that tiny nerve-thread to apprise us of danger transmutes it, and the return pulse that removes us from its presence is a portion of it. The groan of the weary, the shriek of the tortured, the voicéd agony of the babeless mother, all borrow their significance from the same source. The magnificence of the work of a Leonardo da Vinci or a Michael Angelo; the divine creations of a Beethoven or of a Mozart; the immortal Principia of a Newton and the Méchanique Celeste of a Laplace,—all had their existence at some point of time in oscillations of ether in the intersolar space. But all this energy is only a transitory possession. As the sunlight gilds the mountain top and then glances off again into space, so this energy touches upon and beautifies our earth and then speeds on its way. What other worlds it reaches and vivifies, we may never know. Beyond the veil of the seen, science may not penetrate. But religion, more hopeful, seeks there for the new heavens and the new earth, wherein shall be solved the problems of a higher life.

NOTES.

[1] *H. Bence Jones*, Croonian Lectures on Matter and Force, London, 1868.

[2] *Herbert Spencer*, Principles of Biology, New York, 1871, I, 60.

[3] *Küss*, Lectures on Physiology, Edited by Duval and Translated by Amory, Boston, 1875, 2.

[4] "Among the phenomena of life those which are intelligible to us are precisely of the physical or mechanical order."—*Marey*, Animal Mechanism New York, 1874, 7. "All action of which we are immediately cognizant is but the result of the operation of the solar heat upon and through independent and correlative existences." "Conservation of energy makes more and more doubtful the existence of a vital principle, and tends to bring the phenomena of living bodies more and more within the domain of pure physical necessity."—*Acland*, Medicine in Modern Times, London, 1869, 23.

[5] "An animal can no more generate an amount of force capable of moving a grain of sand, than a stone can fall upwards or a locomotive draw a train without fuel.

Frankland, Phil. Mag. IV, xxxii, 182; Proc. Roy. Inst., June 8, 1866; Am. J. Sci., II, xlii, 393, Nov., 1866.

[6] *Haughton*, Medicine in Modern Times, 107. *Lavoisier*, Ib., 113; also Phys. Chem. Schriften, 1785, Bd. III.

[7] *Bischoff* and *Voit*, Die Gesetze der Ernährung des Fleischfressers, Munich, 1860. "They found that the amount of urea eliminated was not in proportion to the exercise of force, but the amount of carbonic acid was so."—Sci. Conf., 174. *Lawes* and *Gilbert*, South Kensington Science Conferences, London, 1876, Biology, 173, 174, "I believe it is now accepted that the elimination of urea is no measure of the muscular force exerted within the body. *Haughton*, loc. cit., 108, "No greater mistake is possible in Physiology than to suppose that the products of the changes in the blood by which mechanical or intellectual work is done, are themselves merely the result of the waste of the organs whether muscles or brain, on the exercise of which that work depends." *Theodor*, Zeitschr. f. Biol., xiv, 51–56; J. Chem. Soc., xxxvi, 74. *Voit*, Ib., 57–160; Ib., 75. Also, Untersuchungen über den Einfluss des Kochsalzes, des Kaffees, und der Muskelbewegungen auf den Stoffwechsel, Munich, 1860. *Fick* and *Wislicenus*, Phil. Mag., IV, xxxi, 485. *Smith, E.*, Phil. Trans., 1859, 709; 1861, 747. *Parkes*, Proc. Roy. Soc., xv, 339; xvi, 44. *Noyes*, Am. J. Med. Sci., Oct., 1867. *M. Foster*, Textbook of Physiology, 3d ed., London, 1880, 471.

[8] *Haughton*, loc. cit., 120.

[9] *Haughton*, Animal Mechanics, London, 1873. On Law of Fatigue, see Proc. Roy. Soc., 1879, 1880; Nature, xxii, 128, 1880; Am. J. Sci., III, xx, 147.

[10] *Du Bois Reymond*, Untersuch. ü. thierische Elektricität, 1848–1860. *Marey*, loc. cit. 22, 50. *Radcliffe*, Dynamics of Nerve and Muscle, London, 1871, 26. *Hermann*, Nature, xix, 561. *Haughton*, Animal Mechanics, 5. *Maudsley*, Physiology and Pathology of Mind, 2d ed., London, 1868, 42. *Voit* and *Theodor*, J. Chem. Soc., xxxvi, 951. The conclusions are: 1st, the muscles are the centre of the formation of CO_2, in health 403 grams being excreted, and in a paralytic 250 grams. 2d, lowering of the temperature from 14.3° to 4.4° increases the CO_2 from 155.0 to 210.7 grams. 3d, the urea was not increased, showing that the non-nitrogenous matter was burned. *Foster*, op. cit., 66, 116, et seq. *Gamgee*, Physiol. Chemistry Anim. Body, London, 1880, 345 et seq.

[11] *Matteucci*, Physical Phenomena of Living Beings, London, 1847, 205, 216, 331.

[12] *E. J. Marey*, loc. cit., 53; Nature, xix, 295, 320; C. R., lxxxiv, 190, 354, 1877.

[13] Students' Text-Book of Electricity, *Noad*, 4th ed., edited by Preece, London, 1879, 159.

[14] *Donders* and *Buys Ballot*, Over de Elasticiteit der Spiren, Utrecht, 1863, 47. Quoted in Animal Mechanics, 2.

[15] *Radcliffe, C. B.*, Dynamics of Nerve and Muscle, London, 1871, 29. *Matteucci*, loc. cit., 216, "The analogies between muscular contraction and the discharge of the torpedo are complete; what destroys, augments and modifies the one, acts equally upon the other." *Marey*, "1st, the rapidity of the nervous agent in the electrical nerves of the torpedo seems evidently to be the same as that of the nervous agent producing motion in the frog. 2d, the phenomenon called by Helmholtz lost time exists also in the electric apparatus of the torpedo and lasts about the same time as in the muscle. 3d, the discharge of the torpedo is not instantaneous but is prolonged about 0.14 of a second; which is in a remarkable degree equal to the duration of the shock of the frog's muscle." Animal Mechanism, 57.

[16] *Wollaston*, Phil. Trans., 1809.—*Haughton*, Anim. Mechanics, 16. "It resembles most nearly the deep hum produced by the blowing fan of a large foundry." It is obtained by gently inserting the extremity of the finger into the ear, bringing at the same time the muscles of the hand and forearm into strong contraction. Brunton places the ball of the strongly contracted thumb against the ear. Sci. Conf., 193.

[17] *Weber*, Muskelbewegung, Wagner's Handwörterbuch. *Minot, C. S.*, Jour. Anat. Physiol., xii, 297, 1878. *Lauder Brunton*, Sci. Conf., Biology, 192–4. *Marey*, Animal Mechanism, 47.

[18] *Marey*, Compte Rendu des Travaux du Laboratoire de M. Marey, Paris, 1877, iii. "1st, a torpedo's discharge is not a continuous current. It is formed of a series of uccessive waves, added one upon another. 2d, each electric wave presents a phase

of suddenly increasing intensity followed by a phase of gradually decreasing intensity, 3d, currents induced by a torpedo discharge are all produced at the beginning of each wave. 4th, there are currents induced on the completion of a circuit, the inverse of the inducing currents, as is shown by the electrometer. 5th, the discharge of the torpedo is analogous to muscular tetanus; every electric wave in the discharge corresponds to a muscular shock." Thus we see that a muscle-shock, like an electric discharge, is produced by a single excitation, the delay being the same, about seven hundredths of a second. The wave, like the shock, increases more abruptly than it decreases, alike in muscle and electric organ. The same agents modify the wave and shock similarly. Heat renders both more energetic up to a certain point, from which both disappear. Cold diminishes both and they both cease at zero. In both, the waves and the shocks run into each other in the same manner. Both suffer from fatigue alike and both are alike affected by poisons. "Does the fact that a voluntary discharge of the torpedo is a complex act not prove that the voluntary contraction of the muscles is also a complex act? Very certainly the comparison of the voluntary contraction of the muscles with the tetanic phenomena produced by electricity, or strychnine, the existence of a muscular sound during the contraction, the quivering or dissociation of the shocks which are produced under the influence of cold,—all these seem arguments in favor of the theory which considers muscular contraction as the result of very frequent shocks; but the complexity of the voluntary discharge of the torpedo, the manner in which the waves composing it succeed each other and are added together, forms a very important confirmation of the numerous presumptions already made." Abstract by Francois Franck, Nature, xix, 295, 320.

[19] *Feddersen*, Pogg. Ann., ciii, 69. *O. N. Rood*, Am. J. Sci., II, xlviii, 153, 1869. *A. M. Mayer*, Ib., III, viii, 136, 1874. The electric spark in air, and probably also the discharge through conductors, is intermittent and consists of a great number of oscillatory movements. In a private communication from Dr. T. A. Edison, he states that muscular tetanus can be produced by rapid vibrations of a purely mechanical character; the effect closely resembling that which results from the secondary current of an induction coil.

[20] *Matteucci*, loc. cit., 195, 252. *M. Foster*, Physiology, 44–46. "When a frog is poisoned with urari, the nerves may be subjected to the strongest stimuli without causing any contractions in the muscles to which they are distributed; yet even ordinary stimuli applied directly to the muscle readily cause contractions." "The activity of contractile protoplasm is in no way essentially dependent on the presence of nervous elements."

[21] *Matteucci, loc. cit.*, 200. "The origin of this current resides in the electric conditions which are produced by the chemical actions of the nutrition of the muscle." *Marey*, loc. cit., 55. "As to the origin of the electric force, we think no one can now see anything in it but the result of chemical actions produced in the interior of the apparatus."

[22] *Prof. Sir Wm. Thomson*, Electrostatics and Magnetism, 1872, 317. *Fleeming Jenkin*, Electricity and Magnetism, 44. "If two metals (as copper and zinc) be plunged in water, the copper, the zinc, and the water forming a galvanic cell, all remain at one potential and no charge of electricity is observed on any part of the system."

[23] *Peclet*, Ann. Chim. Phys., III, ii, 233. *Kohlrausch*, Pogg. Ann., lxxxviii, 465; lxxii, 353; lxxxii, 1. *Buff*, Ann. Chem. Pharm., xlii, 5; xlv, 137. *Becquerel*, Ann. Chim. Phys., xxv, 405; C. R., xxii, 677. *Hankel*, Pogg. Ann., cxxvi, 286. *Gerland*, Ib., cxxxiii, 513. *Du Moncel*, C. R., xc, 964; La Lumière Electrique, ii, 357, 1880. *Pellat*, C. R., xc, 990. *Ayrton* and *Perry*, Proc. Roy. Soc., 1878–9; Phil. Trans., 1879; Nature, xix, 498, 1879. *Everett*, Units and Physical Constants, 146–150, 1879. *Gore*, Nature, xxii, 21. *Edelmann*, Rep. f. Exp. Physik., xvi, 464, 1880. *B. O. Peirce, jr.*, Inaug. Diss., Leipzig, 1879.

[24] *L. Cumming*, Theory of Electricity, London, 1876, 120, *et seq.*

[25] *Peltier*, Ann. Chim. Phys., lvi, 371, 1834. *Tyndall*, Phil. Mag., IV, iv, 419. *Lenz*, Pogg. Ann., xliv, 342. *Bouty*, C. R., xc, 917, 987, 1880.

[26] *Prof. Sir Wm. Thomson*, Phil. Mag., IV, iii, 529, 1852; viii, 62–69; Phil. Trans., iii, 661, 1856. *Jenkin*, Electricity and Magnetism, 187.

[27] *Hoorweg*, Wied. Ann., II, ix, 552, Apr., 1880; Nature, xxii, 90.

[28] *Matteucci*, loc. cit., 200. *Marey*, loc. cit., 55. *M. Foster*, op. cit., 474. "If we admit that the energy of muscular contraction (and with that the energy of all other vital manifestations) arises from an explosive decomposition of a complex substance which we may call real protoplasm, and that this complex protoplasm is capable of reconstruction within limits which may be very wide, we acquire a conception of physiological processes, which if not precise and definite is at least simple and consistent and moreover a first step toward a future molecular physiology."

[29] *Matteucci*, loc. cit., 332. *Prevost* and *Dumas*, *Schwann*, Quoted by *Lauder Brunton*, Sci. Conf., Biol., 191, 192.

[30] *Matteucci*, Op. cit., 332. *Brunton*, Sci. Conf., 191. *Ritter*, Thèse de concours, Strasbourg, 1863. *Küss*, Physiol., 70. *Foster*, Physiol., 61.

[31] *Radcliffe*, loc. cit., viii, ix, 20, 98. *Quincke*, Nature, xxii, 206, 1880.

[32] *Marey*, Op. cit., 39.

[33] *Rouget*, *C. R.*, June, 1867. "The lengthening is produced by a moving cause which is developed in the act of nutrition and is correlative to heat if it be not heat itself." *Engelmann*, Pflüger's Archiv, vii, 33–71; 155–188; xviii, 1–24. Also Hoffman and Schwalbe's Jahresbericht for 1878, 71, 72. [I am indebted for these views of Engelmann to Dr. C. S. Minot of Boston.—*B.*]

[34] *Schäfer*, Sci. Conf., Biol. 171. *Marey*, C. R., lxxxix, 203. *Levon*, Ib., 242. *Richet*, Ib., 792, 956; Nature, xx, 106, xxi, 76. *Couty* and *Lacerda*, C. R., lxxxix, 794, 1034; Nature, xxi, 76.

[35] *Prout*, "This agency is vital and its nature is completely unknown. It is impossible to imagine that the agency of the stomach can be chemical." Bridgewater Treatise, 1834, 493. Quoted by Bence Jones, loc. cit., 59.

[36] *Kühne*, Physiologische Chemie, 1866. *Haidenhain*, Nature, xix, 544. *Bernhard*, J. Chem. Soc., xxxiv, 82. *Defresne*, C. R., lxxxix, 737, 1070; J. Chem. Soc., xxxviii, 330. *Richet*, J. Chem. Soc., xxxiv, 520. *Seegen*, J. Chem. Soc., xxxvi, 548, 549. *Harth*, J. Chem. Soc., xxxvi, 660. See also Am. Chem. Journal, ii, 204–212.

[37] *Matteucci*, loc. cit. "Thin plates of slate or of baked clay" show the phenomena of osmose (page 35); and those of transpiration take place "with tubes of vein, artery, clay, pasteboard and wood" (page 83). *Nasse*, J. Chem. Soc., xxxiv, 519. See also xxxviii, 414.

[38] *Setschinoff*, J. Chem. Soc., xxxiv, 519. See also *Grehant*, Nature, xviii, 106. *Gaule*, Nature, xix, 474. *Fredericq*, The venous blood of the squid (*Octopus vulgaris*) and lobster (*Homarus*) contains a colorless albuminoid cupriferous body, which he calls hæmocyanin. In the gills it forms an unstable compound with oxygen, oxyhæmocyanin, being of a beautiful blue color. The venous blood is colorless; but when the animal respires aerated water, the arterial blood becomes blue. Like hæmoglobin, hæmocyanin breaks up into a proteid substance free from copper, and a cupriferous body analogous to hæmatin. J. Chem. Soc., xxxv, 333; Nature, xxi, 370.

[39] *Marey*, Travaux du Laboratoire, i, 100; ii, 1, 1875.

[40] *Schmidt*, Reichert u. Du Bois Reymond's Archiv, 1861, 545; 1862, 428, 533.

[41] *Hammarsten*, J. Chem. Soc., xxxv, 472; xxxviii, 172; Pflüger's Archiv, xiv, 211; xvii, 413; xviii, 38; xix, 563. See also *Gamgee*, op. cit., 42–53.

[42] *Liebreich*, Ann. Chem. Pharm., cxxxiv, 29.

[43] *Gamgee* and *Blankenhorn*, $C_{160}\ H_{308}\ N_5\ PO_{35}$, J. Chem. Soc., xxxvi, 950; Nature, xxi, 387; Zeitschr. phys. Chem., iii, 260, 1879.

[44] *Radcliffe*, loc. cit., 17. *Du Bois Reymond*, Gesammelte Abhandl., ii, 232, 1877. *Engelmann*, Pflüger's Archiv, xv, 211, 1877.

[45] *Haughton*, Anim. Mechanics, 18, Note.

[46] *Herbert Spencer*, Principles of Psychology, I, 81, et seq. *Clifford*, Seeing and Thinking, London, 1879, 12–17. See also Sci. Conf., Biology, 224.

[47] *Donders*, Sci. Conf., Biology, 224. *Müller*, *J.*, Handbuch der Physiologie des Menschen, Coblentz, 1844, i, 581.

[48] *Helmholtz*, Müller's Archiv, 1850, 276; 1852, 199. *Du Bois Reymond*, Royal Inst. Lecture, 1868. *Haughton*, Anim. Mechanics, 14. Along the motor nerve of the frog, Helmholtz found the velocity of transmission at the rate of 88 feet per second. Along the sensor nerves of man Schelske found it to be at the rate of 97 feet.

[49] *Marey*. Anim. Mechanism, 41, 43. See also Du Bois Reymond's Lecture, "On the Time required for the Transmission of Sensation and Volition through the Nerves," Proc. Roy. Inst., 1866. *Garver*, Am. J. Sci., III, xv. 413, 1878; xx, 189, 1880.

[50] *Lovering*, Proc. A. A. A. S., xxiv, 37, 1876.

[51] See *Preece's* edition of *Noad's* Electricity, 67. On aërial wires the observed speed has varied from 112,680 miles per second on a wire 179 metres long to 816 miles per second on a cable 1,020 kilometres in length.

[52] *Weber*. Quoted by Radcliffe, loc. cit., 18.

[53] *Radcliffe*, loc. cit., 18.

[54] *Gaugain*, Quoted by Lovering, loc. cit., 37.

[55] *Marey*. "We know that electric phenomena are produced in the nerve when it has been excited in a certain way, and that their propagation throughout the nervous cord seems to have precisely the same speed as that of the transference of the nervous energy itself." Anim. Mechanism, 41. *Bernstein*, Untersuch. ü. d. Erregungsvorgang im Nerven- und Muskel-systeme, 1871, has shown that the negative variation or current of action passes along a muscle or nerve from the spot stimulated in the form of a wave, travelling in the nerve at the same rate as the nervous impulse, in the muscle at the same rate as the contraction. See Foster, op. cit., pp. 77, 105.

[56] *Clifford*, Seeing and Thinking, 26. *Du Bois Reymond*, Roy. Inst. Lect., 1866. *Spencer*, Psychology, I, 81.

[57] *Bert*, C. R., lxxxiv, 173. *Foster*, op. cit., 77, 126, 503.

[58] *Bain*, The Senses and the Intellect, 3d ed., New York, 1872. *Maudsley*, Body and Mind, London, 1870. Physiology and Pathology of Mind, 2d ed., London, 1858. *Spencer*, Principles of Psychology, New York, 1871.

[59] *Maudsley*, Body and Mind, 18; Physiology and Pathology, 42, 44, 49, 138. *Bain*, loc. cit., 12. *Clifford*, loc. cit., 77. *Allman*, Nature xx, 393. "Every phenomenon of mind is the result as manifest energy, of some change, molecular, chemical or vital, in the nervous elements of the brain."—"The performance of an idea, like the performance of movement, is a retrograde metamorphosis of the organic element." "Mental action is as surely dependent on the nervous system as the liver function is on the hepatic."—*Maudsley*. "No fact in our constitution can be considered more certain than this, that the brain is the chief organ of mind and has mind for its principal function."—*Bain*. "That consciousness is never manifested except in presence of cerebral matter or something like it, there cannot be a question."—*Allman*.

[60] *J. S. Lombard*, New York Medical Journal, v, 198, June, 1867.

[61] *Hirsch*. Determination telegraphique de la difference de longitude entre les Observatoires de Genève et de Neuchatel. Genève et Bale, 1864. *Donders*, Reichert ü. Du Bois Reymond's Archiv, 1868, 657; Sci. Conf., Biol., 225. *Haughton*, Anim. Mechanics, 15.

[62] *Donders*, Science Conferences, Biology, 226.

[63] *Donders*, Ib., 227.

[64] *Gaskell*, Science Conferences, Biology, 186. *Angelo Mosso*, "Sopra un nuovo metodo per scrivere i movimenti dei vasi sanguigni nell' uomo;" Atti della Reale Accademia della Scienze di Torino, xi, Nov. 14, 1875.

[65] *Barnard*, Proc. A. A. A. S., xvii, 93, 1868.

[66] *Clausius*, Pogg. Ann., Dec., 1854. *Thomson*, Proc. Roy. Soc. Edin., 1852; Phil. Mag., 1852; Feb., 1853. *Tait*, Thermodynamics, Edinburgh, 1868, 29, 58. "No known natural process is exactly reversible and whenever an attempt is made to transform and retransform energy by an imperfect process, part of the energy is necessarily transformed into heat and dissipated, so as to be incapable of further useful transformation. It therefore follows that as energy is constantly in a state of transformation there is a constant degradation of energy to the final unavailable form of uniformly diffused heat; and that this will go on as long as transformations occur, until the whole energy of the universe has taken this final form." *Maxwell*, Theory of Heat, 188. *Balfour Stewart*, Conservation of Energy, New York, 1874, 141–154.

[67] *Hermann*, Nature, xix, 561, 1879; Unters. ü. d. Stoffwechsel, Berlin, 1867.

[68] *Berthelot*, Essai de Méchanique Chimique fondée sur la Thermochimie, Paris, 1879. C. R., xc, 1240, 1880. *Thomsen*, Various papers in Pogg. and Wied. Ann., Ber. Berl. Chem. Ges., etc.

[69] *J. W. Draper*, Jour. Frank. Inst., Sept., 1834; Scientific Memoirs, New York, 1878, 346.

[70] *Lippmann*, Ann. Chim. Phys., V, v, 494, Aug., 1875.

[71] *Gore*, Proc. Roy. Soc., Apr. 22, 1880; Nature, xxii, 21.

[72] *Pouillet*, Ann. Chim. Phys., II. xx, 141. *Becquerel*, Ann. Chim. Phys. xxiv, 342. *Matteucci*, loc. cit., 30. *Quincke*, Pogg. Ann., cvii, 1, 1859; cx, 38, 1860.

[73] *Küss*, loc. cit., 3.

[74] *Beale*, Protoplasm, or Life, Matter and Mind, London, 1870, 108. "This transparent material possesses a remarkable power of movement. It may thus transport itself long distances and extend itself so as to get through pores, holes, and canals too minute to be seen even with the aid of very high powers. There are creatures of exquisite tenuity which are capable of climbing through fluids and probably through the air itself—creatures which climb without muscles, nerves, or limbs—creatures with no mechanism, having no structure; capable when suspended in the medium in which they live, of extending any one part of the pulpy matter of which they consist beyond another part, and of causing the rest to follow."

[75] *Beale*, op. cit., 48.

[76] *Ranvier*, C. R., lxxxix, 318. "Cellular elements possess all the essential vital properties of the complete organism. A primitive fasciculus of striated muscle, which is a cellule, possesses sensibility, motricity and contractility. A gland-cellule (and all cellules are more or less glandular), has the same. Lymphatic cellules digest starch, proteids, and fatty matters which have been absorbed, in consequence of their amœboid activity."

[77] *Allman, G. J.*, Pres. Linnean Society, Nature, xx, 384, 1879.

[78] *Beale*, Op. cit., 33, 55. "Nothing that lives is alive in every part. ****In man and the higher animals the free portion of the nails and hair, the outer part of the cuticle and a portion of the dental tissues are evidently lifeless. ** Of the internal tissues a great part is also in a non-living condition." "This contractile tissue [of the muscle] is not, like the germinal matter which produced it, in a living state." "The nerve fibre is composed of formed material." "The non-living tissue which is thus spun off as they [these oval masses of germinal matter] become separated, is the nerve."

[79] *Beale*, Op. cit., 103.

[80] *Allman*, loc. cit., 392. "Irritability, the one great character of all living beings, is not more difficult to be conceived of as a property of matter than the physical phenomena of radiant energy." "There is no greater difficulty in conceiving of contractility as a property of protoplasm, than there is of conceiving of attraction as a property of the magnet."

[81] *Schützenberger*, J. Chem. Soc., xxxvi, 542. *Foster*, Op. cit., 726–748.

[82] *Acland*, Medicine in Modern Times, 28. "There are virtually no limits to the substances which can be made" [by chemistry]. *Odling*, Animal Chemistry, 1866, 58. "Already hundreds of organic principles have been built up from their constituent elements and there is now no reason to doubt our capability of producing all organic principles whatsoever in a similar manner."

[83] *Thos. Graham*, "On Liquid Diffusion applied to Analysis." Phil. Trans. 1862.

[84] *Maudsley*, Phys. and Path., 46; Body and Mind, 161. See also Nature, xxi, 586, 1879.

[85] *Graham*, loc. cit.

[86] *T. Sterry Hunt*, Am. J. Sci., II, v, 74, 1848; vii, 109, 1849. Chemical and Geological Essays, 179, 180. See also *Dusart*, C. R., May, 1861, 974. *Schoonbroodt*, Ib., May, 1860, 856. *Fischer* and *Boedeker*, Ann. Chem. Pharm., cxvii, 111. *Wolcott Gibbs*, Am. J. Sci., II, xxv, 31, 1858.

[87] *Allman*, Address, Nature, xx, 387.

[88] *J. W. Draper*, Proc. Am. Phil. Soc., May, 1843; Scientific Memoirs, 410; Am. J. Sci., III, iv, 161, Dec., 1872; Nature, xxii, 29, 1880.

[89] *Vines*, Nature, xviii, 110. *Boussingault*, Ib., xviii, 672. *Pringsheim*, Ib., xxi, 85. *Lankester*, Nature, xxi, 557. *Boehm*, J. Chem. Soc., xxxiv, 84, 162. *Macagno*, Ib., xxxiv, 90, 162. *Corenwinder*, Ib., xxxiv, 595; C. R., lxxxvi, 608.

[90] *Bert*, C. R., lxxxvii, 695; J. Chem. Soc., xxxvi, 336.

[91] *Gautier*, *Trecul*, *Chevreul*, C. R., lxxxix, 861, 883, 917, 972, 989.

[92] *Allman*, loc. cit., 390.

[93] *Thistleton Dyer*, Sci. Conf., Biology, 162. *Kraus*, J. Chem. Soc., xxxviii, 57. *Wiesner*, Nature, xix, 161.

[94] *Geddes*, C. R., lxxxvii, 1095, Dec., 1878; Proc. Roy. Soc., xxviii, 449.

[95] *Allman*, loc cit., 390.

[96] *Darwin*, Insectivorous Plants, New York, 1875, 85–135.

[97] *Nägeli*, Ber. Ak. München, 1878.

[98] *Wurtz and Bouchut*, C. R., lxxxix, 425. *Wittmak*, J. Chem. Soc., xxxvi, 1048. *Peckolt*, Ib., xxxviii, 128. Twenty-eight centigrams of this ferment, which Peckoldt calls papayotin, dissolved twenty centigrams of meat in ten minutes.

[99] *Bernhard*, J. Chem. Soc., xxxiv, 82. *Defresne*, Ib., xxxviii, 330. *Baswitz*, Ib., 132. *Krauch*, Ib., 175.

[100] *Boussingault*, C. R., lxxxvii, 277; J. Chem. Soc., xxxv, 73.

[101] *Claude Bernard*, Phenomèues de la vie commun aux Anim. et Veget., Paris, 1879.

[102] *Claude Bernard*, op. cit.

[103] *Schützenberger*, C. R., lxxxviii, 287, 383, 593. *Jamieson*, Nature, xviii, 539.

[104] *Kühne*, Lehrbuch der Physiologischen Chemie, Leipzig, 1866, 274. *Bleunard*, C. R., xc, 612, 1080.

[105] *Vines*, Proc. Roy. Soc. May 13, 1880; Nature, xxii, 91. *Barbieri*, J. prak. Ch., II, xviii, 102; J. Chem. Soc., xxxvi, 272; xxxviii, 342.

[106] *Weyl* and *Bischoff*, Ber. Berl. Chem. Ges., xiii, 367.

[107] *Hammarsten*, J. Chem. Soc., xxxv, 472; xxxviii, 172; Pflüger's Archiv, xvii, 413; xviii, 38; xix, 563.

[108] *Hoppe-Seyler*, Medicinisch-Chemische Untersuchungen, 1866, 162.

[109] *Gamgee*, op. cit., 4, "The proteids of the animal body are all derived directly or indirectly from vegetable organisms which possess the power of constructing them out of the comparatively simple chemical compounds which serve as their food. Such a synthesis never takes place in the animal body, though the latter possesses the power of converting any vegetable or animal proteid into the various proteids which are characteristic of its solids and liquids." *Foster*, op. cit., 474, "The whole secret of life may almost be said to be wrapped up in the occult properties of certain nitrogen compounds." "Pflüger has drawn some very suggestive comparisons between the so-called chemical properties of the cyanogen compounds and the so-called vital properties of protoplasm."

[110] *Pasteur*, C. R., May 3, 1880; Nature, xxii, 48, 1880.

[111] *Archibald*, Nature, xix, 145. *Jevons*, Ib., 338. *Chambers*, Ib., xviii, 567, 619. *Stewart*, Ib., 616; Conservation of Energy, New York, 1874, 98.

[112] *Jevons*, Nature, xix, 33, 97, 196, 588; xviii, 483.

[113] *W. K. Clifford*, "Energy and Force," Nature, xxii, 122, 1880. *S. T. Preston*, "Physical Aspects of the Vortex Atom Theory," Nature, xxii, 56, 1880.

[114] *Clifford*, Seeing and Thinking, 39. "The luminiferous ether is not a fluid like water, but it is a solid something like a piece of jelly." See also *Hall* and *Harkness*, Report on Encke's Comet, Washington, 1871.

[115] *Thomson, Sir Wm.*, Phil. Mag., IV, ix, 36–40. *Stewart* and *Tait*, The Unseen Universe, 104.

[116] *J. F. W. Herschel.* "Familiar Lectures on Scientific Subjects," London, 1867, 282.

[117] *Herschel*, Op. cit., 282. *Sir Wm. Thomson*, Phil. Mag., IV, ix, 36. "The mechanical value of a cubic mile of sunlight [at the earth's distance from the sun] is consequently 12050 foot-pounds, equivalent to the work of one horse power for a third of a minute."

[118] *S. Tolver Preston*, Phil. Mag., V, ix, 356, May, 1880.

[119] *Spinoza*, Quoted by Maudsley, Phys. and Path., 170–172.